by Pauli and Villars.[4] It will be interesting to compare the present situation with the electromagnetic self-energy of the mesons as investigated by Heitler and McConnell.[5]

I wish to express my thanks to Dr. S. T. Ma for many stimulating discussions. I am also indebted to Professor H. A. Bethe for some valuable comments.

* State Scholar of the Government of India.
[1] W. Pauli, and M. E. Rose, Phys. Rev. **49**, 462 (1936).
[2] S. N. Gupta, Proc. Phys. Soc. (to be published).
[3] R. P. Feynman, Phys. Rev. **74**, 1430 (1948).
[4] W. Pauli and F. Villars, Rev. Mod. Phys. **21**, 434 (1949).
[5] W. Heitler and J. McConnell, Nature **164**, 218 (1949).

Nuclear Gamma-Radiation of Cu^{61}

F. Boehm, J. P. Blaser, P. Marmier, and P. Preiswerk
Department of Physics, Swiss Federal Institute of Technology, Zürich, Switzerland
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THE positron spectrum of Cu^{61} has been examined recently by Cook and Langer[1] with a large magnetic spectrometer. The experimental curves of these authors show a deviation from the Fermi distribution which is much larger than for Cu^{64} and it seems possible that not all of this deviation arises from instrumental factors. It is pointed out by different authors[2,3] that Cu^{61} does not emit nuclear gamma-rays which means that the spectrum of Cu^{61} must be simple. On the other hand the measurements of Cook and Langer can hardly be understood without the assumption of a complex spectrum. To examine this discrepancy, we started a search for gamma-radiation in Cu^{61}.

By irradiation of a nickel target with protons from the cyclotron we get very strong sources of Cu^{61}. After chemical separation and precipitation as chloride the Cu^{61} samples have been examined in a magnetic lens spectrometer for conversion-electrons and for photo-electrons. The following gamma-rays have been found:

$$E_{\gamma 1} = (0.652 \pm 0.005) \text{ Mev}$$
$$E_{\gamma 2} = (0.279 \pm 0.005) \text{ Mev}$$
$$E_{\gamma 3} = (0.070 \pm 0.001) \text{ Mev.}$$

The first and the second of these gamma-rays, γ_1 and γ_2, have been detected by photo-electron conversion from a lead radiator (Fig. 1). The relative intensity of these gamma-rays may be estimated by comparison with the photo-lines of the annihilation radiation taking into account the variation of the photoelectric cross section with energy, and the fact that two gamma-rays of the annihilation radiation are due to one positron. One gets for the intensity of γ_1 and γ_2 relative to the total number of decays respectively (9 ± 4) percent and (5 ± 3) percent. The ratio of K-capture to positrons in the 1.205 Mev transition has previously been assumed to be 0.3.

The intensities of γ_1 and γ_2 decay with the half-life of $3.35h$ characteristic of Cu^{61}. Contaminations can therefore be excluded.

The line γ_3 has been found as an internal conversion line in both a magnetic lens and a magnetic semicircular spectrometer. Its K/L conversion ratio was found to be 10 ± 3. Therefore this transition probably has a dipole character. Assuming a K internal conversion coefficient of about 10 percent (Hebb and Nelson), and comparing the line area with that of the positron spectrum, we find the intensity of this gamma-line relative to the number of decays to be (4 ± 2) percent. No harder gamma-radiation than 0.652 Mev could be found.

These gamma-rays give evidence for a complex decay of Cu^{61}. We may assume that the complexity arises from a positron transi-

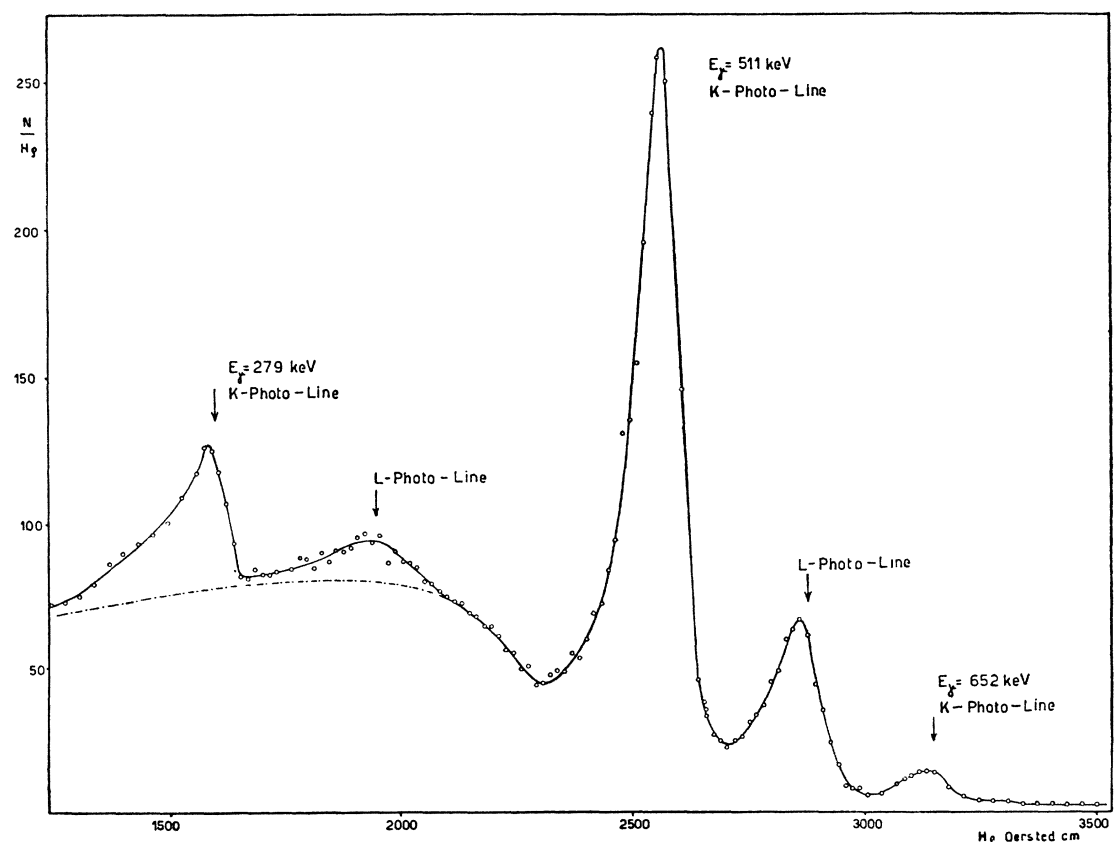


FIG. 1. Photo-electron spectrum of Cu^{61} with lead converter. Dotted curve shows the Compton electron background as measured in Zn^{63} in the same geometry.

tion to a state of Ni^{61} 0.652 Mev above the ground state. The end point energy of this spectrum would be $1.205-0.652=0.553$ Mev. This assumption is in agreement with the findings of Cook and Langer that the positron spectrum shows a deviation for energies lower than about 0.511 Mev. For this energy the ratio of K-capture to positron emission is about 5, which means that in the momentum distribution of the positrons a complexity of about 1–2 percent must be expected.

We wish to thank Professor Scherrer for his kind interest in and active support of this work.

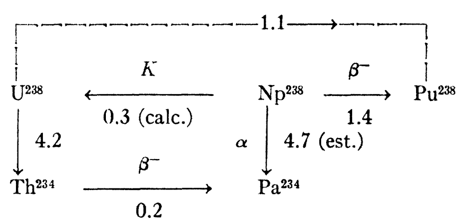
[1] C. S. Cook and L. M. Langer, Phys. Rev. **74**, 227 (1948).
[2] W. Gentner and E. Segrè, Phys. Rev. **55**, 814 (1939).
[3] Bradt, Gugelot, Huber, Medicus, Preiswerk, and Scherrer, Helv. Phys. Acta **18**, 252 (1945).

Half-Life for Double Beta-Decay*

C. A. LEVINE, A. GHIORSO, AND G. T. SEABORG
Department of Chemistry and Radiation Laboratory, University of California, Berkeley, California
November 28, 1949

FIREMAN[1] has reported the results of a rather difficult beta-particle coincidence counting experiment in which the decay of $_{50}Sn^{124}$ to $_{52}Te^{124}$ by the simultaneous emission of two negative beta-particles, with a half-life between 4×10^{15} and 9×10^{15} years, seems to have been observed. This note reports the results obtained from a different and somewhat simpler method of looking for the phenomenon of simultaneous emission of two beta-particles. These results are negative so far and show that this process is considerably less probable in the case chosen by us than in that reported by Fireman.

Our method consists of looking in uranium samples for 90-year Pu^{238} which would come from U^{238} by the double beta-particle mechanism since Np^{238} is heavier than U^{238}, which in turn is substantially heavier than Pu^{238}, in the isobaric triplet $_{92}U^{238}-{}_{93}Np^{238}-{}_{94}Pu^{238}$. This chemical method of investigation is particularly applicable to this isobaric triplet because there appears to be no other mechanism to account for the Pu^{238} should it be found. The energetics of the situation are summarized in the following diagram, where the disintegration energies (in Mev) are derived from sources which may be traced through a recent compilation.[2]



The alpha-disintegration energy of Np^{238} is estimated from alpha-decay systematics.[3]

Our experiment consisted of taking 14 kg of very pure, 6-year old, UO_3 and extracting and separating the plutonium fraction by chemical means. The method consisted essentially of dissolving the oxide in nitric acid and precipitating Pu(IV) with lanthanum fluoride, followed by solution of the lanthanum fluoride and oxidation of the plutonium to Pu(VI), which was extracted into diethyl ether and then re-extracted into water. Similar cycles were repeated five times in order to separate completely from UX_1 and to reduce the amount of lanthanum carrier, after which the final sample was plated out on flat platinum with total carrier weight probably less than 50 micrograms. The use of tracer Pu^{239} in this separation established that the chemical yield amounted to 10 percent.

This final sample was measured for the presence of the 5.51-Mev alpha-particles of Pu^{238} on the alpha-pulse analyzer apparatus in this laboratory.[4] This analysis showed that the counting rate of the Pu^{238} alpha-particles at essentially 50 percent counting yield amounted to 0.00 ± 0.01 counts per minute above background. This indicates that the "half-life" of U^{238} for simultaneous emission of two beta-particles, for which a total energy of 1.1 Mev is available, is greater than 6×10^{18} years.

This experiment could be extended to reach longer half-lives through the use of larger and older sources of uranium such as pitchblende ore. In this case, of course, the plutonium fraction so isolated will contain a certain amount of Pu^{239} as has already been demonstrated.[5] The extraction of plutonium from a ton of pitchblende (50 percent uranium) with 10 percent yield could detect a half-life as long as some 10^{22} years for the same limits of counting accuracy.

This result appears to disagree with that of Fireman although it may not be possible to be positive about this in view of the difference in energies and atomic numbers and possible difference in degree of prohibition involved. The theory for the double beta-decay process sets widely differing ranges of half-life depending upon whether the process can take place without neutrine emission.[6] Fireman's results are in the range predicted for double beta-decay without neutrino emission while our half-life limit seems to be above this predicted range and perhaps points toward the emission of two neutrinos in this process.

A recent investigation[7] of the double beta-transition $_{52}Te^{130}\rightarrow{}_{54}Xe^{130}$, by a similar method in which the xenon present with a tellurium ore was analyzed, also points toward a two-neutrino process, but is subject to experimental uncertainty with respect to the age of and the degree of xenon retention by the ore.

It is a pleasure to acknowledge the assistance of Dr. L. B. Magnusson in the chemical procedure.

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[1] E. L. Fireman, Phys. Rev. **75**, 323 (1949).
[2] G. T. Seaborg and I. Perlman, Revs. Mod. Phys. **20**, 585 (1948).
[3] Perlman, Ghiorso, and Seaborg, Phys. Rev. **74**, 1730 (1948); Phys. Rev. **77**, 26 (1950).
[4] Ghiorso, Jaffey, Robinson, and Weissbourd, National Nuclear Energy Series, Plutonium Project Record Vol. 14B "The Transuranium Elements: Research Papers," Paper No. 16.8 (McGraw-Hill Book Company, Inc., New York, 1949).
[5] G. T. Seaborg and M. L. Perlman, J. Am. Chem. Soc. **70**, 1571 (1948); National Nuclear Energy Series, Plutonium Project Record Vol. 14B "The Transuranium Elements: Research Papers," Paper No. 1.3 (McGraw-Hill Book Company, Inc., New York, 1949).
[6] W. H. Furry, Phys. Rev. **56**, 1184 (1939).
[7] M. G. Inghram and J. H. Reynolds, Phys. Rev. **76**, 1265 (1949).

On the Reaction $Mg^{24}(p,\gamma)Al^{25}$

T. GROTDAL, O. M. LÖNSJÖ, AND R. TANGEN
University of Oslo, Oslo, Norway
AND
I. BERGSTRÖM
Nobel Institute for Physics, Stockholm, Sweden
December 5, 1949

THE bombardment of ordinary magnesium with protons gives the following reactions:

$$\begin{array}{lll}(1) & Mg^{24}(p,\gamma)Al^{25} & Q=2.3\text{ Mev}\\ (2) & Mg^{25}(p,\gamma)Al^{26} & Q=8.4\text{ Mev}\\ (3) & Mg^{26}(p,\gamma)Al^{27} & Q=7.3\text{ Mev.}\end{array}$$

These reactions have been investigated by Curran and Strothers.[1] They separated the reactions by the positrons accompanying some of the resonances, ascribing these resonances to reaction (2). Hole, Holtsmark, and Tangen[2] found eight sharp resonances between 200 and 500 kv. Tangen,[3] using the same technique as